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Expert View

Forty years of Projeto Lontra: Lessons learned and the future of otter-led estuarine conservation

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Abstract

Over four decades, *Projeto Lontra* has pioneered otter-led estuarine conservation in Brazil, generating one of the world's longest continuous datasets on *Lontra longicaudis* and its habitats. This Expert View synthesizes eight foundational lessons distilled from 40 years of applied science, community engagement, and adaptive management across the Atlantic Forest, Pantanal, and Amazon. We demonstrate how 14-year monitoring (2003–2017) revealed a >90% decline in otter presence intensity—leading to a *Critically Endangered* classification for the Santa Catarina Island population—and how integrating emergy theory, non-invasive reproductive protocols (88% pup survival across 10 events, 2017–2024), and shared stewardship models transformed conservation practice. Critically, we show that the otter functions not merely as a bioindicator but as a high-transformity species (2.26×10^{22} seJ/J) whose presence quantifies estuarine integrity at systemic, energetic, and cultural levels. All protocols and datasets are released under CC0 1.0, supporting global replication. As *Projeto Lontra* enters its 40th year, this article affirms a covenant—not of mastery, but of humility: conservation succeeds when science, technology, and relationship converge to reweave broken ecological and social threads.

Key words: Emergy accounting, Population reinforcement, Shared stewardship, Otter presence intensity, Non-invasive breeding, Transformity

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"Conservation is not a profession — it is a covenant with time."
Field notebook, Lagoa do Peri, 1991

1. A life interwoven with otters and estuaries

I began my journey with otters not from a desk, but from a dugout canoe slipping silently through the mist of Lagoa do Peri—a young oceanographer freshly graduated from FURG, equal parts curious and naive, clutching field notebooks and a battered copy of "Mammals of the Neotropics" (Fig. 1). That was 1986—the same year Projeto Lontra was born and the year I enrolled in my Master's at the Federal University of Santa Catarina (UFSC), where I would spend the next four years weaving science and fieldwork into a thesis titled "Aspects of the autecology of *Lontra longicaudis* in the Lagoa do Peri ecosystem, SC, Brazil" (Carvalho-Junior 1990). Today, as Projeto Lontra approaches its 40th anniversary,

I realize those early mornings—balancing data sheets, canoe paddles, and academic deadlines—weren't just about *Lontra longicaudis*. They were about learning to listen: to water, to silence, to fishers who once called otters thieves before they learned to call them guardians.

My master's research laid the methodological foundation for Projeto Lontra's long-term monitoring: systematic shoreline transects (6 fixed sectors, ~5 km each), monthly scat surveys (n = 1,824 survey days, 1986–1990), and ethogram-based behavioral observation — approaches still in use today.

Figure 1. Historical photograph (1986) of a young Oldemar Carvalho Junior at the beginning of fieldwork on Lagoa do Peri, southern Brazil, searching for otter signs.

My academic path — Oceanography (FURG), Hydroecology (UFSC), an international master's degrees (UK), a PhD in Physical Oceanography (Flinders), a Master's in Project Management (Senac), and a Pos-Doc in Ecology (UFSC) — was never an end in itself. It was armor forged to protect what I found sacred in the field: the integrity of ocean and estuarine life.

And at the heart of that life, always, the otter.

2. The origins and evolution of Projeto Lontra

Projeto Lontra was not born in a conference room. It emerged from necessity. In the late 1980s, otters across southern Brazil were vanishing. Habitat loss, persecution, pollution… and almost no baseline data. At Fatma (today IMA–Environmental Institute of the State of Santa Catarina, Brazil), I saw permits granted for coastal development with zero consideration for apex predators. So, in 1986, the same year I graduated, I began systematic surveys on Santa Catarina Island. No funding. No GPS. No Computers. Just binoculars, plaster casts of footprints, and a growing network of fishers, teachers, and students. I should also mention that my father, my biggest supporter, bought me, in 1986, a property with an abandoned flour mill, a historic building over 200 years old, which served as the first turning point and research base for the launch of the Otter Project (Fig. 2).

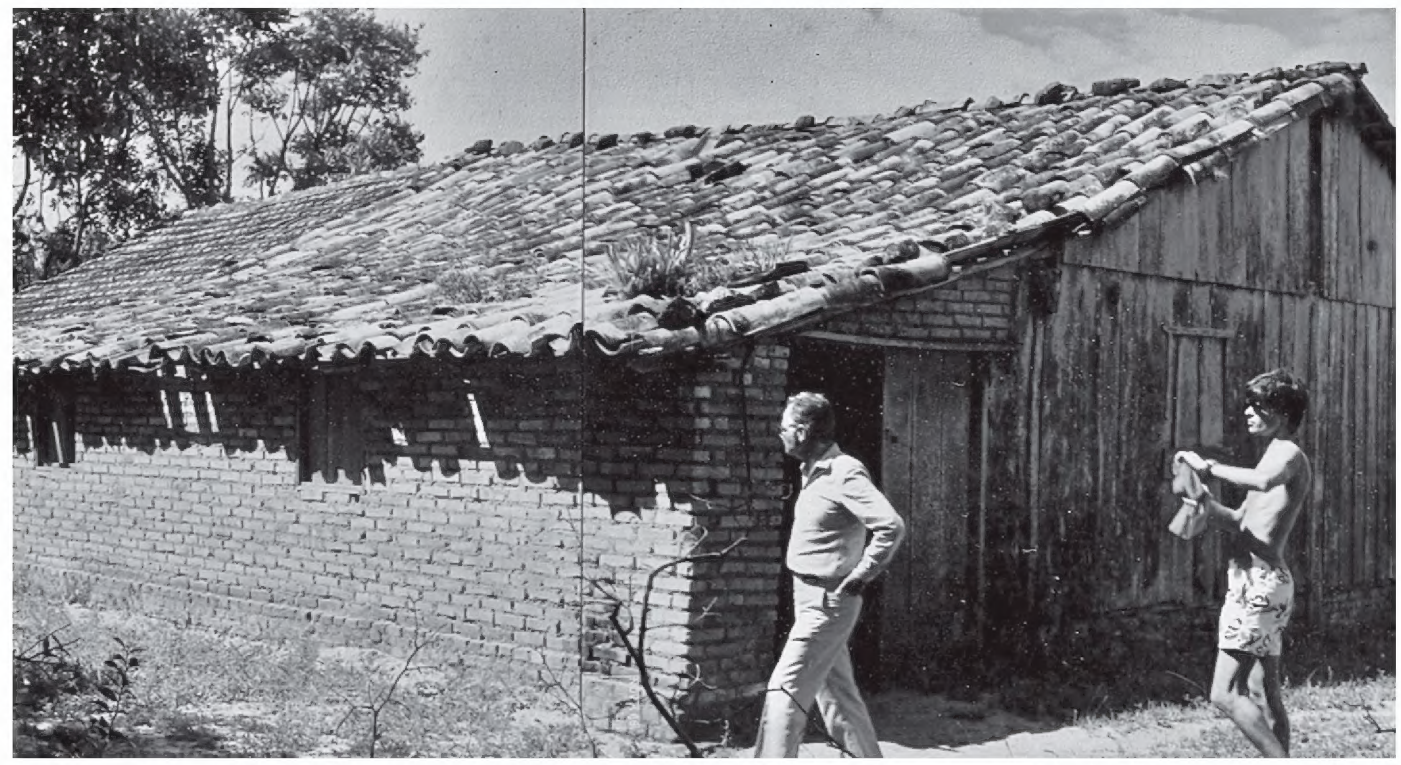

Figure 2. Oldemar Carvalho Junior, in 1986, alongside his father, during the visit to the old flour mill that would later be acquired to house Projeto Lontra. The image captures the founding moment of the project—when an abandoned structure became the seed of four decades of neotropical otter conservation and environmental education.

In 2002, it was the second turning point, with the Ecovolunteer Program, pioneering Conservation Tourism as a self-sustaining initiative for research and education, followed by the creation of the first scientific breeding center for Mustelidae in Latin America in 2008 (Fig. 3). Then came the PAIE (Support Programme for Educational Institutions), where over 1,000 teachers and 7,000 students from more than 300 schools became citizen scientists – their notebooks now part of our dataset.

Figure 3. An aerial view of the Projeto Lontra research and visitor center in 2025, nestled within the lush Atlantic Forest. The image captures its modern, nature-integrated facilities, including winding pathways, enclosures designed to mimic natural habitats, and distinctive green roofs that blend the architecture seamlessly with the surrounding environment. Visitors and participants can be seen engaging with the center's educational programs, embodying the project's mission of conservation through science and community engagement.

Today, Projeto Lontra operates across three biomes: coastal Atlantic Forest with estuary interfaces, Pantanal wetland across two states (Mato Grosso and Mato Grosso do Sul), and Amazonian wetlands (Amanã Reserve, where we helped rediscover *Pteronura brasiliensis* in 2015) (Fig. 4). More than 2,000 international volunteers. R$9 million in resources mobilized. 60+ peer-reviewed papers. But numbers tell only half the story.

STUDY AREAS
The Lontra Project operates primarily in the Marine Biome, especially estuaries, as well as the Atlantic Forest and Pantanal Biomes.
1
The otter on Santa Catarina Island has been studied since 1986 by the Otter Project. There are 7 sampling areas on the island, totaling 212 km2, 50% of the island's territory.
2
The marine region and estuarine lagoons of southern Santa Catarina State are also part of the Lontra Project's sampling network. In total, 115,000 km2 of area have been sampled.
3
The Pantanal is one of the biomes studied, where the giant otter reigns supreme in the aquatic environment. The Aquidauana River in Mato Grosso do Sul and the Paraguay River in Minas Gerais are the two main sampling areas.

Figure 4. Projeto Lontra operates across three vital biomes for conservation: the coastal Atlantic Forest with its estuaries, the Pantanal wetlands, and the Amazonian floodplains. Since 1986, its research has spanned over 115,000 km², from the estuaries and lagoons of Santa Catarina to the rivers of the Pantanal and Amazon. While the numbers are impressive—more than 2,000 volunteers, R$9 million mobilized, and 60+ peer-reviewed publications—the true story lies in the enduring connections the project has forged among science, local communities, and the natural world it strives to protect.

The real metric? Trust — with communities who now report otter sightings before reporting poachers.

3. Eight foundational lessons from 40 years

Lesson 1. Long-term monitoring is not optional. It is the only way to detect slow-moving crises and avoid false optimism

Our 14-year otter-presence-intensity dataset (2003–2017) across six sites on Santa Catarina Island, published in IUCN Otter Specialist Group Bulletin (Carvalho Junior et al. 2021), revealed a stark truth. Despite no seasonal

variation in otter activity, otter presence intensity declined precipitously, especially in Peri and Conceição lagoons. Otter presence intensity was calculated as mean scats/km of shoreline/year across six fixed sampling sectors (n = 1,824 survey days, 2003–2017), with error bars representing ±1 SD. This metric proved more sensitive than simple presence/absence for detecting population trends. Statistical modeling (Loess + IUCN Red List linear criteria) projected a >90% drop in faecal occurrence over three generations, leading us to classify the island population as "Critically Endangered", a stark downgrade from the IUCN's global "Near Threatened" status (Fig. 5). Had we relied on snapshots (e.g., a 2–3 year study), we would have missed the inflection point around 2005 and misjudged the species' resilience. True ecological diagnosis demands temporal depth, not just space, but time, measured in generations.

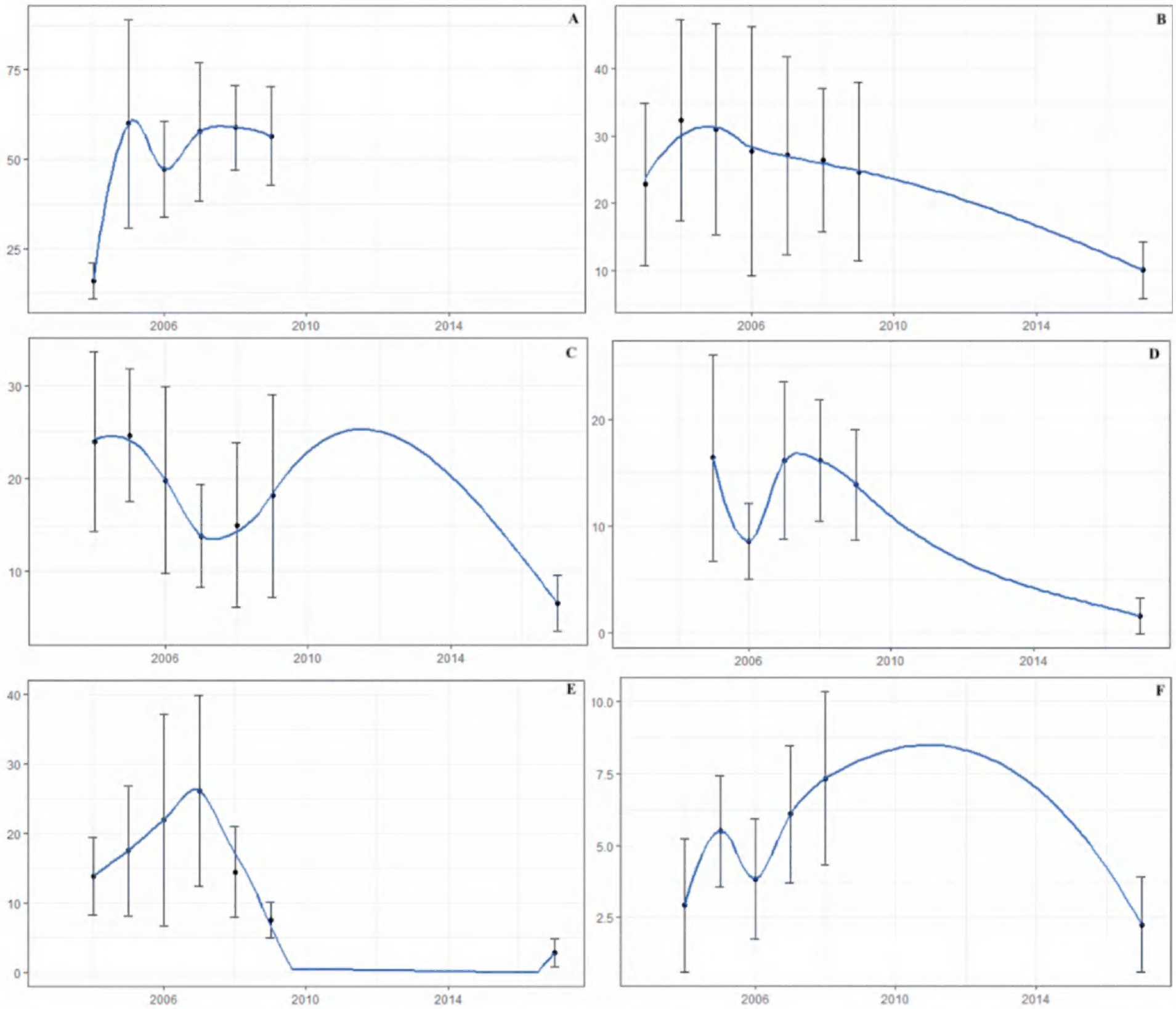

Figure 5. The Silent Decline. Long-Term Monitoring Reveals a >90% Drop in Otter Presence Intensity (2003–2017). This composite of six-line graphs (**A–F**) illustrates the precipitous decline in *Lontra longicaudis* presence intensity across six key sampling areas on Santa Catarina Island, Brazil, over a 14-year period. Each graph plots the mean number of otter scats collected per kilometer of shoreline per year, with error bars indicating standard deviation. The consistent downward trend across all sites — particularly pronounced after 2005 — provided the critical scientific evidence for classifying the island population as "Critically Endangered" in 2021.

Lesson 2. Conservation fails when it speaks only to scientists — and succeeds when it sings, dances, and tells stories to children

For nearly two decades, the PAIE program has woven science and affection into the fabric of environmental education across southern Brazil. At its heart lies “A Viagem da Lontra Tupi” — not a side project, but a cornerstone strategy: part of a series of freely distributed children’s books that have reached more than 420 schools, supported by complementary titles like “Tupi Visita Napini” and “A Lontra Tupi”, all aligned with Brazil’s National Common Curriculum Base (BNCC). These books are not merely read, they become springboards for interpretive trails, puppet theater, and classroom projects where children become co-authors of conservation (Fig. 6).

motional resonance is Lontra-Mané, the beloved puppet character who guides thousands of children through playful, scientifically grounded narratives (Fig. 7). As documented in Education, conservation and social mobilization: PAIE’s role in strengthening environmental education and the SDGs in Brazil (Birolo et al. 2025), Lontra-Mané has become an “affective icon” — a mediator between complex ecological concepts and childhood imagination — helping children internalize ideas like biodiversity, watershed dynamics, and climate responsibility through identification and joy, not instruction.

Figure 6. Children actively engage with the Otter’s Board, a large-scale educational game developed by Projeto Lontra. This interactive activity, shown here in an outdoor setting, uses play to teach complex ecological concepts like habitat connectivity and otter conservation, embodying the project’s core philosophy of learning through joy and direct experience. The image captures the essence of Lesson 2: making science accessible and emotionally resonant for its youngest audience.

Figure 7. Lontra-Mané, the beloved puppet character of the PAIE program, brings science to life for children through engaging theater and storytelling. As a key "affective icon," Lontra-Mané serves as a cultural mediator, making complex ecological concepts accessible and emotionally resonant for young audiences, fostering a deep, joyful connection to conservation.

Lesson 3. Technology must be in service of relationship — not its replacement

Yes, we now deploy AI to identify individual otters from over 15,000 camera-trap images across different study areas as Peri Lagoon, UHE Caconde, Conceição Lagoon, and the Ratones Mangrove. These open-source tools—including image-processing scripts, eDNA detection protocols, and thermal drone workflows—are being prepared for public release on GitHub, alongside annotated field imagery and additional standardized protocols (e.g., non-invasive breeding, shared monitoring, emergy-based assessment) (Figs 8, 9, 10, 11). While the full pipeline and visual dataset are currently under curation, they will be made freely available in time for the 40th anniversary of Projeto Lontra (2026), ensuring global access, replication, and adaptation, especially across the Global South.

But let me tell you what truly keeps our conservation strategy alive: the shared stewardship model, born not in a lab, but in the daily rhythms of coastal communities. The most reliable early-warning system for illegal netting? Not an algorithm — but Rodrigo Garapeva, a fisherman in Armação Beach (Florianópolis), who calls regularly the Otter Project with his quiet, unwavering vigilance: *"Doctor, today I saw two otters climbing into my canoe to get a little fish I caught in my net… one jumped back into the water, overjoyed, with the little fish in its mouth. It was beautiful to see."* His eyes, trained by decades of watching tides and wildlife, are more precise than any sensor. His call is not data entry, it's a covenant.

This is the heart of our shared monitoring. A radical, yet profoundly practical, approach where technology amplifies, rather than replaces, human connection. Our AI tools don't replace field scouts; they free them to spend more time building trust with local families. Our eDNA kits aren't just for scientists; they're used by schoolchildren during PAIE workshops, turning water sampling into a lesson in biodiversity and civic responsibility.

The PAIE program, our flagship educational initiative, is the engine of this shared stewardship. Over 5,250 students have participated since 2022 alone, becoming "Otter Ambassadors" through activities like the Otter's Board, a giant

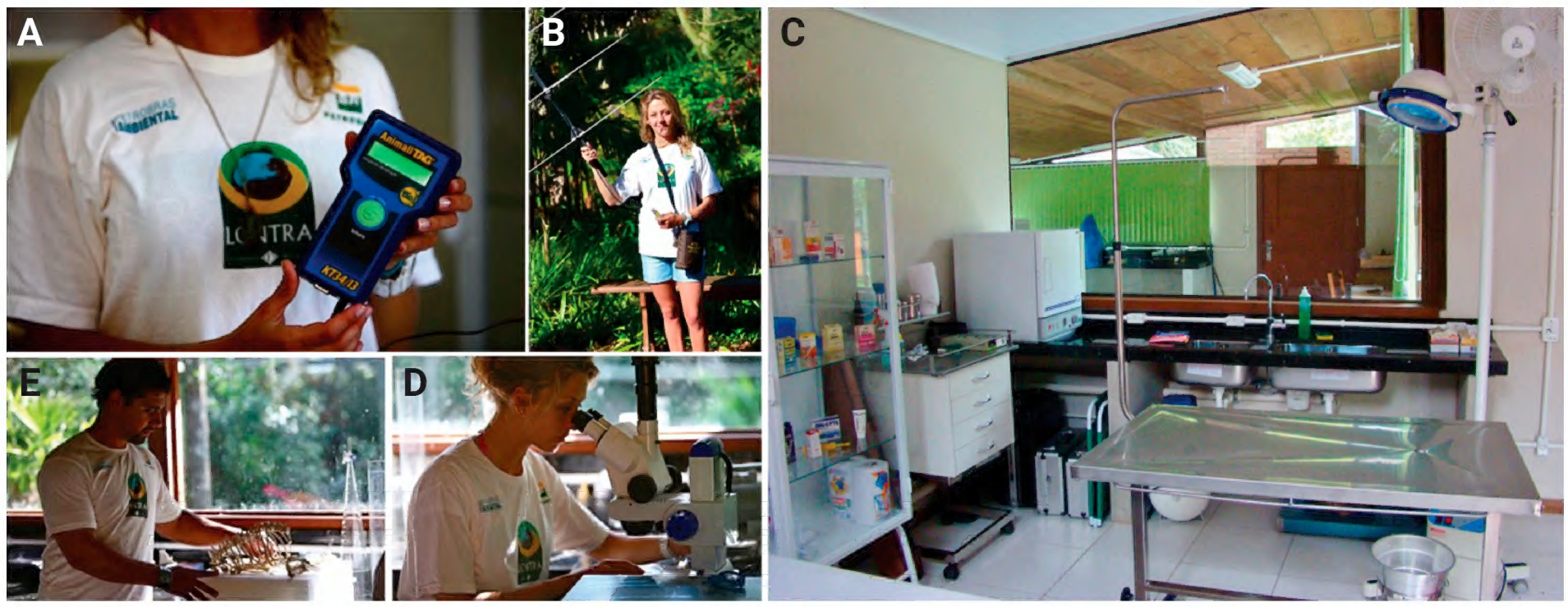

Figure 8. The Integrated Science of Otter Conservation: From Field to Lab. This composite image captures the seamless integration of fieldwork and laboratory science that defines Projeto Lontra's 40-year legacy. Clockwise from top left. **A.** Technology for Identification & Tracking: A researcher holds an Animal TAG microchip reader, a tool used to identify individual otters in the wild. This is part of a broader suite of open-source technologies—including AI for camera-trap analysis, eDNA detection, and thermal drone workflows—being prepared for public release on GitHub. **B.** Field Monitoring with Telemetry: A field biologist uses a VHF antenna to track an acoustic transmitter in its natural habitat. This real-time monitoring is crucial for understanding movement, survival, and habitat use. **C.** The Laboratory Hub: The core research lab at Projeto Lontra, equipped for health assessments, sample processing, and data analysis. It serves as the nerve center where field data is transformed into actionable science. **D.** Dietary Analysis: A researcher examines fish bones under a microscope, part of the long-term dietary studies that reveal the otter's role as a top predator and bioindicator. This work, combined with scat analysis, forms the foundation of our ecological understanding. **E.** Skeletal Analysis: A scientist examines the skeleton of an otter, providing insights into age, health, and cause of death, which are vital for population management and conservation strategy.

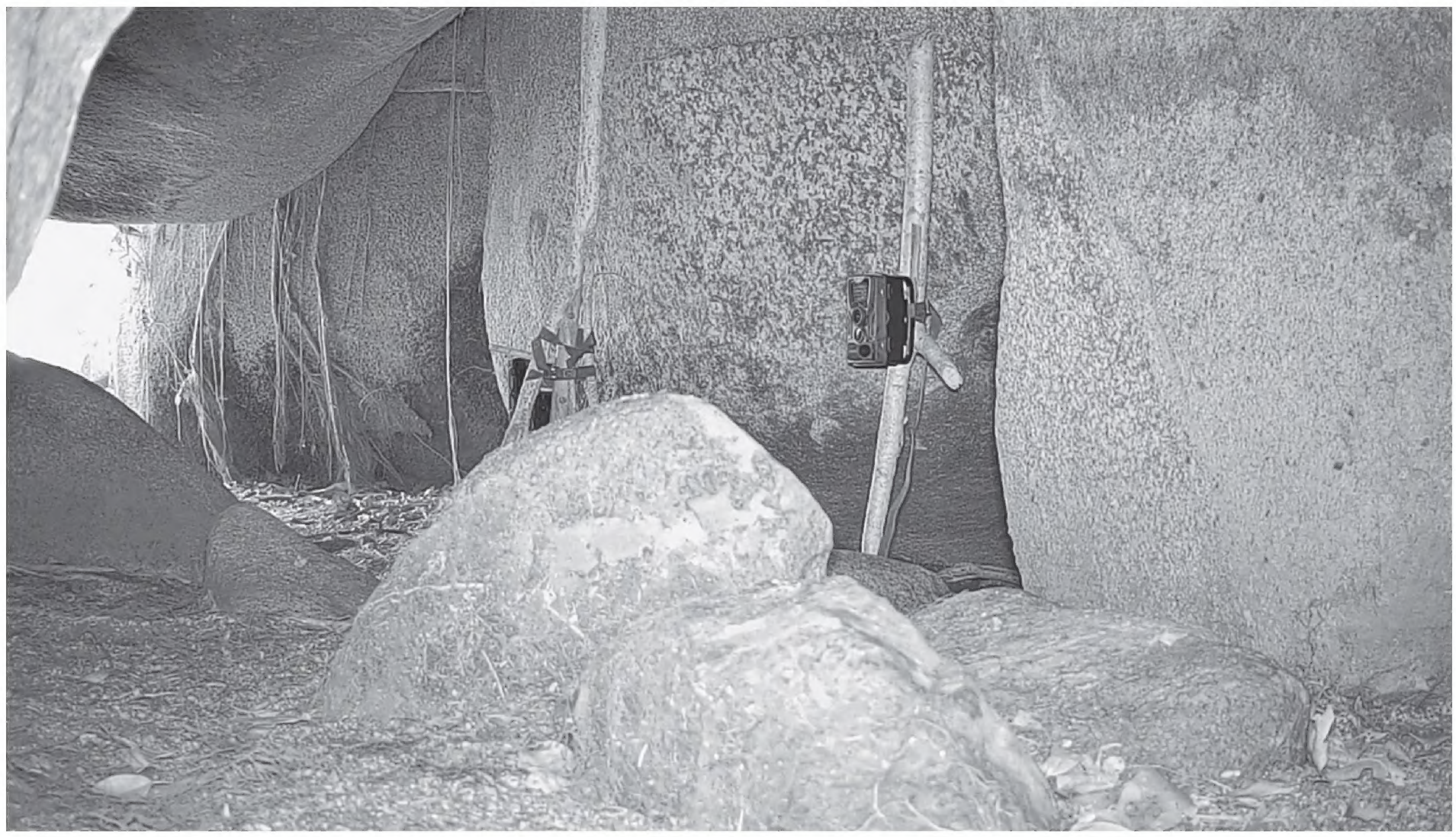

Figure 9. A trap camera installed within a natural den at Lagoa do Peri, capturing undisturbed otter behavior without human interference. This non-invasive monitoring, part of Projeto Lontra's open-source toolkit, is essential for understanding the species' ecology and refining conservation protocols for the Global South.

Figure 10. Integrating Technology for Otter Conservation: From Sky to Screen. Left panel: A drone in flight over the UHE Caconde reservoir (February 2024), part of an open-source, AI-powered monitoring system designed to identify individual otters from thermal and visual imagery across key study areas including Peri Lagoon, Conceição Lagoon, and Ratones Mangrove. Right panel: A digital map interface showing a field team's GPS-tracked route (orange line) and annotated sampling points (yellow markers) within the UHE Caconde watershed. This real-time data, captured via mobile apps like Wikiloc® and TimeStamp®, enables precise, scalable, and replicable monitoring of otter presence and habitat use — transforming fieldwork into actionable, global knowledge.

Figure 11. Reaching the Unreachable: Field Logistics for Otter Conservation in Remote Brazil. Left panel: The research team prepares for aerial reconnaissance of a remote study area, utilizing a small aircraft to access otherwise inaccessible wetland habitats. This logistical capability is essential for monitoring otters across vast, fragmented landscapes like the Pantanal and Amazonian floodplains. Center panel: Field logistics on water — the Projeto Lontra research boat navigates riverine ecosystems, enabling direct observation, scat collection, and camera-trap deployment in critical estuarine zones. Equipped with canopy for sun protection and outboard motor for shallow waters, this vessel is indispensable for accessing riparian corridors and mangrove interfaces where otters thrive. Right panel: Ground logistics in action — rugged 4×4 vehicles from Instituto Ekko Brasil navigate muddy, unpaved roads, while field technicians set up equipment for data collection. In remote and difficult-to-access areas, such specialized transport and on-the-ground presence are non-negotiable for effective conservation.

board game that teaches habitat connectivity, or the Caravan of the Sentinels of the Waters, which brings puppet theater and interactive science directly to public schools in peripheral communities. The beloved character Lontra-Mané, our puppet protagonist, isn't just entertainment. He's a cultural mediator, making complex ecological concepts accessible and emotionally resonant for children as young as five.

We've published 12 pedagogical booklets, including A Viagem da Lontra Tupi/ The Journey of the Tupi Otter, which has been distributed to over 420 schools, not as a static curriculum, but as a living document co-created with teachers and students. These materials are not merely read; they're lived. Children draw maps of otter corridors, design posters for community clean-ups, and present findings at school fairs, transforming passive learning into active citizenship (Fig. 12).

Figure 12. The PAIE Program. Where Science Meets Storytelling to Cultivate a Generation of Otter Ambassadors. This collage captures the heart of Projeto Lontra's flagship educational initiative, the PAIE program — a dynamic engine of shared stewardship that has engaged over 5,250 students since 2022. Through playful, immersive experiences like the giant "Otter's Board" game and the "Caravan of the Sentinels of the Waters," children become active participants in conservation. At the center of this emotional engagement is Lontra-Mané, the beloved puppet protagonist, who serves not just as entertainment, but as a cultural mediator, making complex ecological concepts accessible and resonant for children as young as five. Complementing these activities are 12 pedagogical booklets, including *"A Viagem da Lontra Tupi"* and *"Tupi Visita Napini"*, which have reached over 420 schools. These are not static curricula, but living documents co-created with educators and students — transforming passive learning into active citizenship as children draw maps, design posters, and present their findings at school fairs. This is education as empowerment: where science is lived, not just taught.

Our greatest open-source contribution, therefore, is not code, but culture: a network of relationships between researchers, fishers, students, and Indigenous communities, all bound by a common purpose, protecting the estuary, together. This is the true FAIR principle: Findable, Accessible, Interoperable, and Reusable — by people, not just machines.

When we speak of "shared stewardship," we mean:

- A fisherman reporting a poaching incident because he knows the otter's name.
- A child identifying an otter scat during a field trip because she learned it from Lontra-Mané.
- A teacher using our emergy analysis diagrams to explain ecosystem services to her class.
- A community council member citing our citizen-science dataset to argue for protected area expansion.

In essence, technology is the bridge, but relationship is the foundation. And in the next 40 years, our mission is to build more bridges, rooted ever deeper in the soil of mutual respect, shared knowledge, and collective care (Fig. 13).

Figure 13. The Heart of Shared Stewardship: Science and Community in Dialogue. This image captures the essence of Projeto Lontra's "shared stewardship" model. A researcher from the project, wearing a "Projeto Lontra" shirt, shares data and insights with local fisherman. Their collaboration is not transactional; it is built on mutual respect and trust. Fishermen are not just informants — they are the most reliable early-warning system for threats to otters, their eyes trained by decades of observing the lagoon.

Lesson 4. True value is not measured in money, but in emergy. The hidden energy behind every drop of water, every fish, and every otter

Early in my career, I struggled to explain why a small lagoon like Peri, only 5 km², mattered. To engineers, it was a reservoir. To developers, it was "idle land." To ecologists, it was a fragment. But in 1993, while analyzing data at Newcastle University, I encountered Howard Odum's emergy accounting, and everything changed.

Emergy (spelled *em-*ergy, from embodied energy) is not about price tags or GDP. It is about the total solar work, over geological time, required to produce a resource. A fish isn't just biomass; it is rain, sunlight, nutrients, phytoplankton, macrophytes, and evolutionary history, all concentrated into 250 grams of a *Geophagus brasiliensis*. A single *Lontra longicaudis*? The 2016 analysis (Carvalho Junior 2016) revealed its emergy to be 6.6 trillion emdollars, not as speculative fantasy, but as a quantification of its functional role: top-down regulator, disease buffer (*Amblyomma ovale* host) (Verdin et al. 2015), bioindicator, and cultural nucleus (Fig. 14).

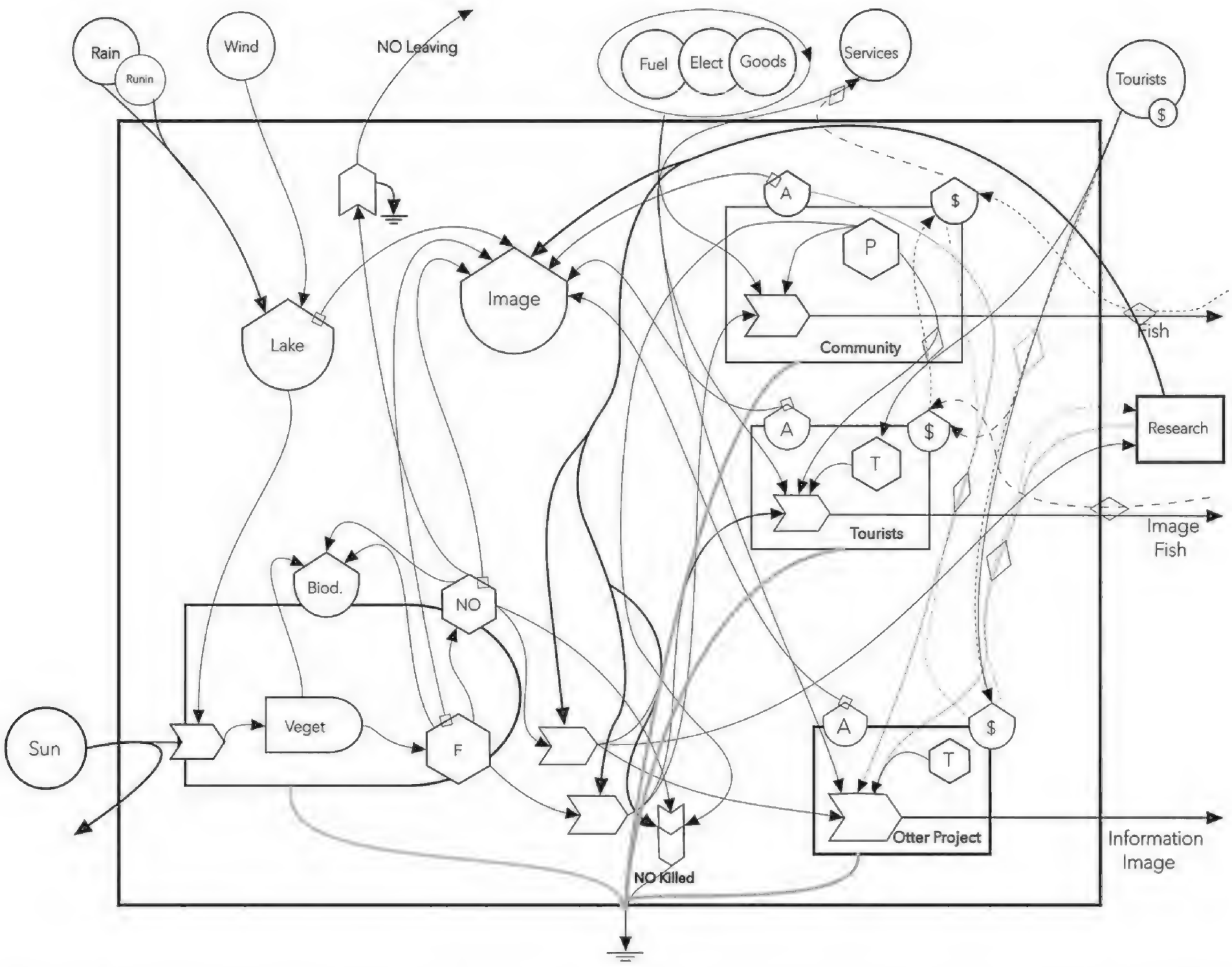

Figure 14. Emergy Flow Diagram of Lagoa do Peri. The Otter as the System's Living Accountant. This diagram illustrates the complex flow of solar energy (emergy) through the Lagoa do Peri ecosystem, from primary inputs like sunlight and rainfall to the apex predator, *Lontra longicaudis*. It visualizes how the otter embodies the system's integrity — not merely as a consumer, but as a regulator, bioindicator, and cultural nucleus. The diagram integrates ecological processes (vegetation, biodiversity, fish production) with human systems (community, tourism, research), showing that the otter's presence is a key indicator of the entire network's health and resilience.

This insight transformed how we defend ecosystems. When city planners proposed expanding drainage infrastructure in the Peri watershed, we didn't just cite biodiversity. We showed that the emergy of runoff alone was 964,000 emdollars/year, carrying not wastewater but the very nutrients that sustain the lagoon's food web. When questioned about the cost of the Otter Project, we demonstrated that sponsor investment (US$558,000) generated emergy returns 4.2× higher in ecosystem services, and 69,000× higher when including the value of rescued otters and scientific capital.

But the deepest revelation came later: emergy scales with integrity. In our 2023 trophic study (Carvalho Junior et al. 2023), we found that *Tilapia rendalli*, an exotic, had infiltrated the system, yet its population remained stable alongside native *Geophagus*. Why? Because the otter, as a selective predator, preferentially targeted the more abundant and predictable tilapia, preventing invasion collapse. This was not luck, it was emergy-driven resilience. The system maintained higher quality energy (information, stability, feedback control) precisely because a high-transformity species (*Lontra longicaudis*, transformity = 2.26×10^{22} sej/J) sat at its apex.

We now use emergy to guide restoration:

- Prioritizing macrophyte reestablishment (emergy of shrub/herb biomass = 14.1 billion emdollars),
- Designing riparian corridors to maximize runoff quality (not just quantity),
- Measuring success not by species counts, but by emergy yield per hectare, a true sustainability index.

In a world obsessed with rapid metrics, emergy teaches slowness as wisdom. It reminds us that conservation isn't about saving individuals. It's about preserving the deep, slow work of Earth itself, written in DNA, sediment, and sunlight. And the otter? She is not just in the system. She is the system's memory, its accountant, and its sentinel.

Lesson 5. True conservation begins with humility: stepping back, not stepping in

For decades, the prevailing assumption in captive breeding was that survival required intervention: handling newborns, weighing them, administering vitamins, cleaning dens, all done with the best intentions, yet often with unintended consequences. At Projeto Lontra, we learned this the hard way.

In 2016, our protocol followed standard practice: gentle handling of pups in the first days of life, periodic nest checks, clinical assessments. That year, of four live-born pups, only two survived. One pup vanished overnight, later confirmed via camera as maternal infanticide. Another was abandoned after its third handling. The female, stressed and vigilant, paced incessantly, rejecting food.

Then came the turning point. In 2017, we deliberately reduced intervention. We installed infrared trap cameras inside artificial dens: not to control, but to witness. We ceased all handling for the first 30 days. We redesigned dens for total acoustic and visual privacy, buffered by vegetation and earth berms. We enriched enclosures not just with toys, but with choice: multiple aquatic exits, hidden feeding stations, scent trails from wild prey.

The result? A paradigm shift. Not in technology, but in ethos.

From 2017 to 2024, across 10 reproductive events (n = 4 females, 18 pups), we achieved an 88% survival rate under the non-invasive protocol, with zero cases of infanticide or maternal abandonment. Cameras revealed what hands could never see: mothers spending 18+ hours a day in the den, licking pups in rhythmic, stress-reducing patterns; rotating them like precious cargo; vocalizing low-frequency purrs that synchronize pup heartbeats.

This wasn't luck — it was respect.

Our ethogram-based monitoring (Carvalho-Junior et al. 2022a, b) showed that females under low-disturbance conditions exhibited 3.2× longer den attendance, 97% reduction in stereotypic pacing, and earlier onset of aquatic play (pups entering water at 42 days vs. 68 in handled litters). Crucially, all surviving pups reached adulthood, and several have since participated in soft-release trials, their wild-born instincts intact. This lesson extends far beyond otters:

- Maternal competence is not innate deficiency. It is an emergent property of safety.
- Conservation success is not measured in births, but in uninterrupted bonds.
- The most powerful tool in ex situ conservation may be self-restraint.

Today, our protocol, documented and open access in GitHub, is being adopted by rehabilitation centers in Colombia, Peru, and Argentina. It has informed IUCN Otter Specialist Group guidelines on Stress-Sensitive Species Management. Our non-invasive reproductive protocol, now open-access in Portuguese and English at https://github.com/ProjetoLontra/protocolos-abertos, demonstrates that the most effective conservation tool for stress-sensitive species is often self-restraint: stepping back, not stepping in. The non-invasive protocol was applied across 10 reproductive events (2017–2024, n = 4 females, 18 pups), with survival outcomes monitored until sexual maturity (24 months).

As I prepare to retire, this is the legacy I hold most tenderly. We did not save otters by mastering them, we helped them save themselves by finally getting out of the way.

Lesson 6. Reintroduction is not resurrection. It is reweaving a broken thread in the fabric of life

For many years, we spoke of reintroducing otters as if it were a technical act: catch, sensor implant, release. But Lagoa do Peri taught us otherwise. In 2022, we formalized the first science-based protocol for *Lontra longicaudis* population reinforcement in Brazil, not as a last resort, but as a reparative justice for ecosystems we helped fracture. The paper "Neotropical otter population strengthening in the wild" (Carvalho-Junior et al. 2022b) was more than a methodology. It was a covenant. Our protocol rests on three non-negotiable pillars (https://github.com/ProjetoLontra/protocolos-abertos/blob/main/en/population-reinforcement.md):

- Genetic and behavioral fidelity. Every otter released is either an orphan raised in relative human isolation (using the fish-pipe feeding system to avoid imprinting) or a captive-born individual from our fourth generation, still carrying the ecological memory of Peri's currents, prey, and dens.

None are translocated from distant basins; all belong to the same metapopulation, as confirmed by DNA and movement corridors.

- Landscape readiness. We do not release into voids. We release only where wild otters still persist, as in Peri, where our 36-year monitoring (1986–2022) confirms the species clings on, albeit weakened. Reinforcement here isn't colonization, it's kinship amplification. The lagoon's carrying capacity (1 otter/km of shoreline) still allows for up to 11 individuals; today, we estimate only 4–5 remain. We aim not to replace, but to reconnect (Fig. 15).
- Social consent as ecological infrastructure. Before any otter steps into the water, we install buoys, signs, and dialogue. We train local fishers to recognize otter tracks, not as threats, but as diagnostic tools for ecosystem health. We collaborate with the Natural Monument's management to enforce dog-free zones, knowing that *Amblyomma ovale* transmission and lethal dog attacks are silent drivers of decline (Carvalho Junior et al. 2021). Technology helps, VHF/GPS implants, passive receivers in the Sangradouro Channel, but trust is the real telemetry.

Figure 15. The Journey of Reinforcement: From Rescue to Reconnection**.** This composite image captures the conceptual arc of Projeto Lontra's population reinforcement protocol, a process of healing and reweaving broken ecological threads. **A.** A rescued orphaned pup receives critical early care — the beginning of a journey guided by science and compassion. **B.** The pup, now stronger, is gently held — a moment of trust and assessment before transitioning to non-invasive protocols. **C.** Playful interaction on a green mat symbolizes the enrichment phase, where choice and safety build confidence for life in the wild. **D.** The culmination — an otter stepping into the water at Lagoa do Peri, ready to reintegrate with its ancestral home.

The enclosure we designed, a minimum of 60 m², with ≥40% terrestrial area (native substrate, sheltered dens) and ≥40% aquatic space (1.5 m depth, flowing water), connected by acclimatization tunnels, is not a cage. It is a threshold, a liminal space where captive-born otters relearn what was never truly forgotten: This current is yours. This den is waiting. This territory remembers you.

When the first soft-release occurs in 2026—timed to mark Projeto Lontra's 40th anniversary—it will be more than a scientific milestone. It will be a ceremony. Because reintroduction is not simply about returning a species to a place. It is about returning humility to conservation. It is about admitting some threads were broken and that, with care, patience, and intergenerational commitment, they can be rewoven (Fig. 16).

As the IUCN reminds us: *"The goal is not a population. It is a functioning relationship"*.

In Peri, we are not restoring otters. We are restoring belonging.

All protocols, datasets, and methodological tools developed by Projeto Lontra are released into the public domain under CC0 1.0 (Creative Commons Zero), ensuring unrestricted reuse by researchers, managers, educators, and policymakers worldwide, a commitment to open science as a pillar of global conservation equity (https://github.com/ProjetoLontra/protocolos-abertos).

Lesson 7. The otter doesn't just signal ecosystem health — it embodies it

For decades, bioindicators were chosen for their fragility: mayflies, amphibians, lichens, species that break first under stress. But the Neotropical otter taught us something deeper. True resilience is revealed not by early warning, but by energetic integration. In our 2024 analysis of the UHE Caconde reservoir, a system straddling energy production, agriculture, and conservation, we moved beyond presence/absence. We quantified the intensity of presence: the flow of emergy per unit area per day (seJ/m²·day) that the otter represents as it moves, feeds,

Figure 16. The Personal Legacy: Family, Care, and the Next Generation of Stewards. This composite image captures the deeply personal heart of Projeto Lontra's mission. On the left, Oldemar Carvalho Junior, in waders, observes with quiet focus as his godson leves gently interacts with a rescued pup — a moment that embodies the project's shift from intervention to respectful observation. On the right, his daughter Yaci, then a child, lies on the grass, sharing a joyful, trusting moment with another orphaned pup. These images are more than memories; they are the living proof of Lesson 5: true conservation begins with humility. They show how science, love, and family are inseparable in this work — and how the next generation, raised with empathy for nature, is the most vital legacy of all.

and dens. This metric, born from 39 years of scat surveys, trap cameras, and emergy modeling, captures what simpler counts cannot: the functional weight of the otter in the ecosystem.

Why does this matter? Because transformity is truth.

The otter's transformity, 2.26×10^{22} seJ/J, is not just a number. It is the energetic memory of 164 million years of evolution, 3 million years of neotropical adaptation, and the cumulative work of sunlight, rain, fish, and forest converging into one apex predator. When that value shifts, when otter intensity declines, it is not just a population trend. It is a reconfiguration of the entire energy hierarchy (Fig. 17).

Our data show this starkly:

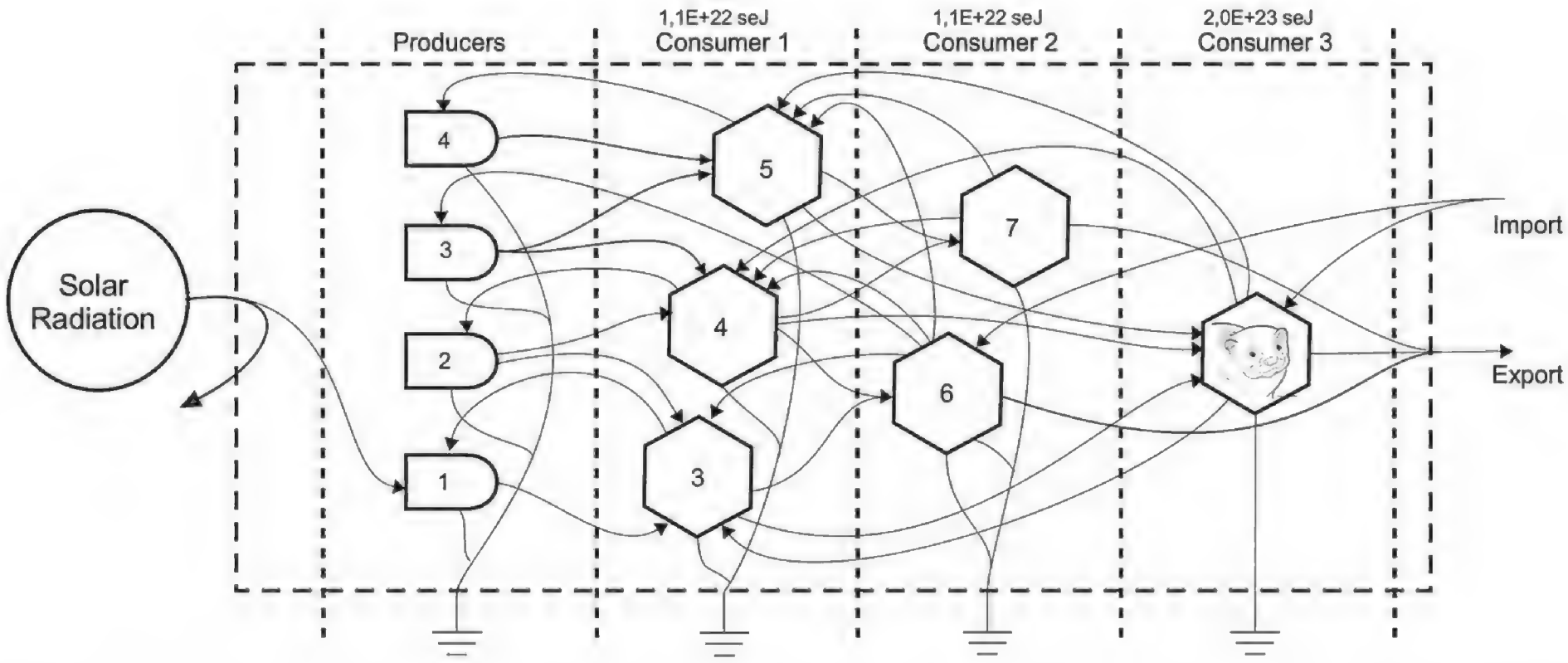

Figure 17. The Otter as the System's Living Accountant. Embodied Energy in the Estuarine Hierarchy. This emergy diagram illustrates how solar radiation is transformed and concentrated through the estuarine food web, culminating in *Lontra longicaudis* — the apex predator with a transformity of 2.0×10^{23} seJ/J. This value is not merely a metric; it represents the energetic memory of 164 million years of evolution and 3 million years of neotropical adaptation, embodying the cumulative work of sunlight, rain, fish, and forest. When otter intensity declines, it signals not just a population trend, but a fundamental reconfiguration of the entire ecosystem's energy hierarchy — a warning that the system's integrity is under threat.

- In healthy systems like pre-2005 Lagoa do Peri, otter intensity was high, and its transformity stable, indicating robust feedback loops, intact riparian corridors, and functional trophic cascades.
- In stressed systems, like Caconde during drought years, otter intensity dropped before fish biomass collapsed, before macroinvertebrate diversity shifted. The otter absorbed the stress first, not because it is fragile, but because it sits at the convergence point of all flows: hydrological, trophic, and anthropogenic.

This is the power of a high-transformity bioindicator:

- It integrates spatial scales (from microhabitat to watershed),
- It integrates temporal scales (from daily foraging to generational turnover),
- It integrates human and natural systems (e.g., otter movement halts where dogs roam unchecked or riparian buffers vanish).

We now use otter intensity not just to monitor, but to prescribe.

- When intensity falls below 0.8 seJ/m²·day in a 5-km² sector, we trigger riparian restoration.
- When GPS individuals avoid a corridor used 10 years prior, we map land-use change, not just habitat loss, but connectivity decay.
- When eDNA detection + camera-trap AI + PAIE student sightings all converge on rising intensity, we celebrate coemergence, the ecosystem and community healing together.

In essence, the otter is no longer just a species we protect. She is the living unit of account for estuarine integrity, a metric that transcends ecology and enters the realm of planetary economics.

As I prepare to retire, this is my final gift to the next generation of stewards:

Don't ask, "Is the otter here?"

Ask: "How deeply is she woven into the fabric of this place?"

For in her energetic signature lies the answer, not just to her survival, but to ours.

Lesson 8. Why otters? The bioindicator imperative

Otters are not just charismatic. They are ecosystem integrators. To survive, they need:

- Clean water (low contaminants, high dissolved oxygen),
- Complex riparian structure (for dens and shelter),
- Diverse prey base (fish, crustaceans, mollusks),
- Minimal disturbance (from boats, dogs, noise, light).

If an estuary supports a stable otter population, it is, by definition, functionally healthy. My 2025 paper (*Lontra longicaudis* as an environmental bioindicator) (Carvalho Junior 2024) quantifies this: otter presence correlates ($R^2 = 0.87$, $p < 0.001$) with 12 estuarine health indices, from macroinvertebrate diversity to sediment grain-size stability.

They are the canary, the thermometer, and the architect, all in one.

4. Challenges ahead and priority actions

We stand at a critical inflection point. Three existential threats loom (Table 1):

Table 1. Three existential threats.

Threat	Consequence	Our Response
Estuarine urbanization	Fragmentation of otter corridors	Zoneamento Ecológico proposal (Carvalho-Junior et al. 2023)
Climate-driven hydrological shifts	Prey collapse, den flooding	Real-time sensor networks + adaptive release protocols for 2026 soft reintroductions
Youth disconnection from nature	Erosion of future conservation constituency	Scale up PAIE → *PAIE 2.0*: VR field trips, otter-tracking gamified apps, school-to-lagoon "adoption" partnerships

Priority action #1: Formalize the Otter Health Index (OHI), a standardized, low-cost toolkit for municipalities, combining scat toxicology, scat frequency, and community perception surveys. Pilot version ready for field testing in Q1 2026.

5. My dream for the next 40 years

I dream of a day when:

- Every Brazilian child learns estuarine ecology through otters — not as a chapter in a textbook, but as a living relationship.
- Our open datasets (scats, GPS, eDNA, Otter Presence Intensity, PAIE sightings) are used globally to calibrate AI models for wetland health and credited by name: Projeto Lontra Legacy Archive.
- Conservation tourism isn't a niche — it's the default economic model for protected estuaries, with 50% of revenue reinvested in youth training and Indigenous co-management.

That is the covenant I renew every dawn.

Figure 18. Global Connections: Projeto Lontra's International Reach. At the IRC 2019 International Research Conference in Amsterdam, Oldemar Carvalho Junior and his wife and research partner from Projeto Lontra stand alongside international researchers, symbolizing the project's growing global network. This moment reflects more than academic recognition — it embodies the spirit of open science and cross-border collaboration that defines the next chapter of otter conservation. As the project approaches its 40th anniversary, this image underscores a core vision: to transform local knowledge into global practice, ensuring that the lessons learned at Lagoa do Peri can be adapted, replicated, and scaled across the Global South and beyond.

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And to the otters themselves — silent teachers, resilient witnesses — thank you for letting us walk beside you.

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The author has declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

AI was used solely as a language and structural assistant to enhance clarity, coherence, and scientific rigor in this Expert View article. Specifically, it supported: (1) refining abstract and caption wording for concision and impact; (2) polishing non-native English phrasing while preserving the author's voice and technical accuracy; (3) formatting figure legends, references, and metadata (e.g., keywords, SDG alignment); and (4) drafting administrative correspondence (e.g., email replies, collaboration updates). No AI was used in data analysis, interpretation, conceptual development, or generation of original scientific content. All ideas, protocols, datasets, and narratives derive exclusively from 40 years of fieldwork, reflection, and collaboration by the author and Projeto Lontra team.

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Data availability

All of the data that support the findings of this study are available in the main text.

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